Modeling of the constant-current stimuli response of a bio-robot for long-term motion control

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Abstract— **Bio-robots continue to receive attention because of their small size and low power consumption. Unfortunately, it currently faces two major obstacles before practical application. The first is the habituation issue, insects are difficult to be effectively controlled for a long time by electrical stimuli signals. The other one is the lack of model for motion control. In this research, we established a stimuli-response model for cockroach bio-robot based on long time current. A more convenient optic lobe implantation method has been proposed, which has lower attenuation and better stimuli effect. Constant electrical stimuli also significantly increased the number of effective controls for crawling. A cockroach bio-robot stimuli distance response model was established and validated with experiment data. Five parameters were including in this model, namely sex, length, weight, current amplitude and equivalent stiumated-number. This model can predict the movement distance of biological robots well.**

I. INTRODUCTION

Bio-robot is a kind of robot that combines the insect and artificial devices. Compared with micro-robots made up of electromechanical systems [1], bio-robots only need simple electrode implantation and application of electrical stimuli signals. For example, the locust [2], the beetle [3]–[5] and the jellyfish [6], can be controlled by implanting electrodes into muscle. Relies on precise contraction of muscles to accomplish localized movement control of the body. The crab [7] and the cockroach [8] were capable of movement under human command based on nerve electrical stimuli. After being stimulated, the animal would make a stress reaction and complete the movement of turning and advancing. Therefore, neural electrical stimuli is more suitable for controlling bio-robots that use the entire body as a mobile platform.

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There are currently three kinds of neural interface for cockroach bio-robot. The most common interface is antennae. The cockroach's antennae is connected to electrodes by method of antennae-excision [9] or non-surgical [10]. The other one is cerci, as the cerci is also an acute sensory organ of the cockroach [11]. The third is trunk ganglion, which is usually used for forward control and in conjunction with other interfaces [10].

The habituation issue is a major obstacle for bio-robots to be put into practical applications. It refers to that the insect's (like cockroach) response will weaken and disappear under repetitive stimuli. That means bio-robot's effective control can only be sustained for a short period of time. To mitigate the effects of cockroach bio-robot's habituation, Ma [12] proposed the method of alternating antennae-to-cerci. Li [13] proposed a new algorithm through dynamically adjusting the voltage amplitude of stimuli. But they are all improvements based on tradtional single-phase voltage. Neither of them replaced single-phase voltage signal with better electrical signal. In terms of the capacity of long-lasting stimuli, it has long been concluded in the field of functional electrical stimuli that bidirectional electrical signals are superior to unidirectional electrical signals [14], [15], constant-current signals are superior to constant voltage signals [16], [17]. However, due to the limitations in the size and performance of backpacks, not just Ma and Li, almost all current studies use single-phase voltage as stimuli signal [18], [19]. Bio-robot need electronic backpacks capable of outputting bidirectional constant-current.

The lacking of basic model is another large constraint for cockroach bio-robot. Almost all the studies related to cockroach model are the explorations of cockroach biology habits [20], [21] or the algorithms proposed to imitate the behaviour of cockroach populations [22], [23]. They are both conducted on cockroaches in natural state. Weight-bearing and electrical stimuli—the two most important factors of bio-robot are not taken into account. It's important to understand that the cockroach bio-robots and the cockroaches in natural state are two completely different concepts. As a kind of unconventional control object, cockroach bio-robot's basic movement process —stimulated-motion response hasn't been quantitatively described by anyone.

In this research, we proposed a low-habitation stimuli method and modeled the stimuli response with the consideration of attenuation. The stimuli method was implemented by using constant-current stimuli and optic lobe implantation. Meanwhile, cockroaches were tested in response to constant-current stimuli and compared with data based on voltage sig-